Continuous, In-Line Processing of Stable CdS/CdTe Devices

W. S. Sampath, K. L. Barth, and R. A. Enzenroth
Materials Engineering Laboratory, Department of Mechanical Engineering, Colorado State University
Fort Collins, Colorado 80523

Abstract

A continuous in-line process suitable for large volume manufacturing of CdS/CdTe PV devices has been demonstrated at the pilot scale level. The process is scaleable, uniform and reproducible. Devices with efficiency greater than 12.5% and good stability have been fabricated on unmodified LOF TEC15 substrates.

1. Introduction

It is estimated that nearly 40 times the current yearly production is required to sustain a PV module manufacturing capacity that can contribute just 5 % of the current electricity generated [1]. Since 1991, our wok on CdTe PV has led to advances in the areas of: (a) device structure, (b) manufacturing process, and (c) hardware designs suitable for large scale manufacturing. These advances have been demonstrated on a unique pilot scale system. The best practices of developing manufacturing technology, such as lean manufacturing, have been followed in the engineering of the pilot system.

2. Pilot Scale Demonstration

The pilot system is a continuous, in-line system for processing 3 X 3 inch substrates. The steps of glass heating, all semiconductor depositions, chloride heat treatment and ohmic contact formation are incorporated in one chamber operating at a pressure of 40 mTorr nitrogen. An automated belt transports the substrates from air into vacuum and through the different processing modules and then back to air. The processing is synchronous with a cycle time of 2 minutes. Details of our work can be obtained form the website of our laboratory [2].

Because of the high degree of reproducibility, the pilot system is also an excellent research platform to develop a detailed understanding of stability, process yield and efficiency. It has been observed that process conditions have a significant effect on efficiency and stability.

3. Results From the Pilot Scale System

The pilot system has been used extensively to understand the process, hardware requirements and device performance. Nearly 3000 substrates have been processed with this system. The substrates are unmodified low cost, soda lime glass, commercially available from Libbey Owens Ford (LOF TEC15) with no antireflection coating. The substrates are heated to 530° C in two minutes. The high degree of thermal uniformity in the system has resulted in no thermal cracking of the glass during processing.

Cells have been consistently fabricated with 10.5% to 12.5% conversion efficiency. One cell has an NREL verified 12.44% efficiency and a 71% fill factor. The highest efficiency measured on devices produced with this system is 13.5%. Higher efficiencies are possible with further optimization.

The stability of the devices is very promising. Nearly 500 devices are undergoing accelerated indoor stress testing. The stress conditions consist of 1 sun illumination, 65º C, OC with 5 hours of illumination out of an 8 hour cycle. A randomly selected set of 17 devices, processed at the optimum condition, has demonstrated an average efficiency of 10.5% after 3500 hours of stress. One of these devices had an initial efficiency of 12.15% and maintained an efficiency of 11.35% after 3504 hours of stress. Figure 1 shows the current density vs. voltage curve for this cell after stress. A plot of dV/dJ vs. the inverse current density in light (not shown) has no curvature indicating no evidence of the formation of a blocking contact during stress.

Stability may be adequate for outdoor applications based on estimates from the literature [3,4]. However, exact correlation between indoor and outdoor conditions is being developed in our laboratory. Many cells are currently being exposed to outdoor conditions in a unique sealed demountable fixture and the results of the outdoor tests will be correlated with the accelerated indoor test results. Most of the published outdoor results have been done on modules. Modules can have additional failure mechanisms such as: interconnect degradation, busbar degradation and encapsulation failure [4]. The outdoor tests underway in our laboratory avoids these additional failure mechanisms and will allow the direct comparison of accelerated indoor stress tests to outdoor performance.

4. Process Yield

High efficiency devices are processed with high yield and consistent stability with the pilot system. The statistical distribution of the initial efficiency of devices processed with the pilot system is shown below in Figure 2. This data is from 4 substrates, with 15 cells per substrate, from 3 different process runs and no cells omitted. The lighter shaded group shows two outlying cells with low efficiency. This was due to a systematic problem in the cleanliness of the substrate leading to poor film growth and device shunting. The darker shaded group shows the initial efficiencies after this problem was corrected. Efforts are currently underway to further improve uniformity.

The pilot system is currently being upgraded to continuously operate for long duration (8 hours or more). Devices will be randomly selected during long runs and tested for starting efficiency, stability and yield.

5. Studies for Scale Up

Studies for processing larger substrates have been initiated. Conceptual designs and mathematical models of the process modules for larger substrates are being developed. The heat and vapor flux on systems processing larger substrates will be exactly the same as the process conditions that have been developed on the pilot system. This will avoid any unanticipated technical difficulties in scaling up to larger substrate sizes.

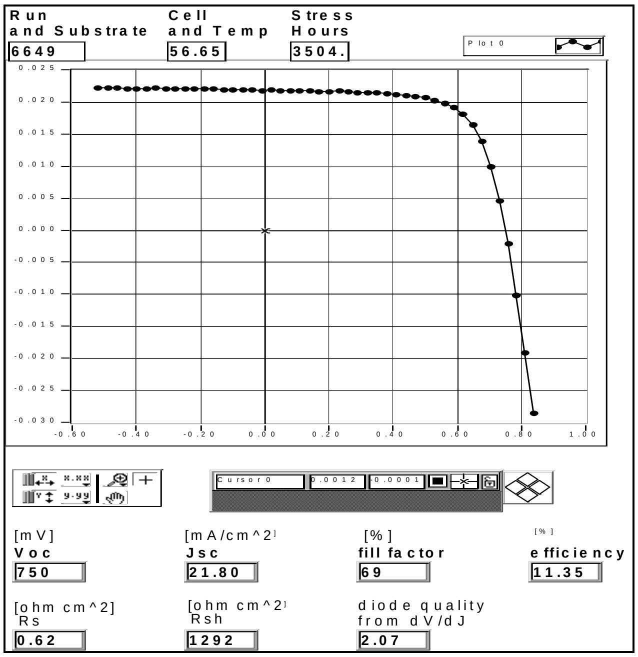

Fig. 1 Cell JV after 3504 Hours of Stress

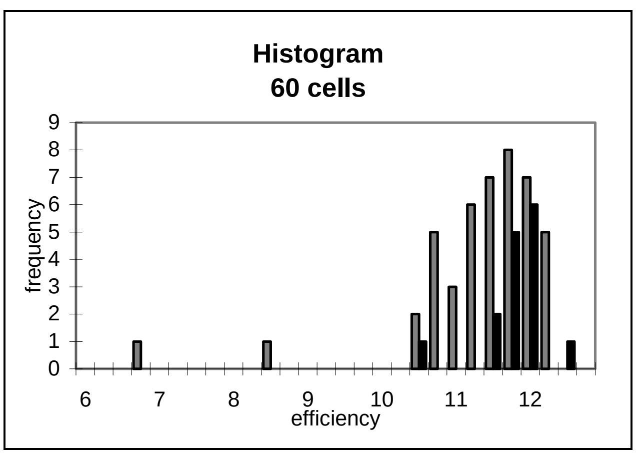

Fig. 2 Histogram of Initial Cell Efficiencies

6. Advantages for Large Scale Manufacturing

The technology demonstrated in our laboratory has the potential for the rapid expansion of PV manufacturing capacity to meet the growing needs of the market. The technology has the potential for substantial improvements in yield, capital productivity, labor productivity and overall manufacturing efficiency for the following reasons:

- The process modules for glass heating, semiconductor deposition and ohmic contact formation are very similar. The process modules can be easily fabricated and can be standardized.
- The capital cost of the vacuum system is low because only modest vacuum is required.
- Metallization is performed using a high throughput industrial process.
- Materials usage is excellent (near 100%).
- No liquid waste and virtually no solid waste are generated.
- Novel interconnection technology is low cost and high throughput.

7. Future Work

In addition to the scale up efforts described earlier, efforts are underway in our laboratory in the following areas:

(a) Understanding stability mechanisms,
(b) Developing statistical quality control methods,
(c) Optimizing the process to further increase efficiency and stability,
(d) Measuring yield during many long duration (more than 8 hour) processing runs and
(e) Exploring technology transfer.

8. Conclusions

A continuous in-line process has been demonstrated at the pilot scale level. High efficiency devices with good stability have been processed with high yield.

9. Acknowledgments

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10. References

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